INTRODUCTION

In 1830, citing his need to educate introductory anatomy students about human cranial variation, Samuel Morton "resolved to make a collection" of skulls that represented the races of mankind. Thus began the first significant American collection of human skeletal remains. By the time of Morton's death in 1852, this collection had burgeoned to include 918 crania, with 51 more in transit.

Though the series was initially accumulated with educational motives in mind, it also served as a basis for Morton's researches, which were featured in such classics as *Crania Americana*, *Crania Aegyptiaca*, *Squier and Davis' Ancient Monuments of the Mississippi Valley*, and in Henry Rowe Schoolcraft's ethnographic treatise concerning Indian tribes in the United States. Morton and his collection thus initiated a significant tradition in American physical anthropology: the collection and study of human skeletal series to gain new knowledge about mankind. Though physical anthropology as a discipline has grown and diversified remarkably over the past 150 years, our heritage unquestionably derives from these early comparative investigations of human skeletal remains.

The significance of Morton's work rests primarily on the fact that his observations were made on such a large collection of crania. This allowed comparisons impossible for earlier scholars such as Blumenbach, whose results were then said to be "invalidated by the small number of
specimens relied upon . . .”2 And, as might be expected, the accumulation of additional comparative skeletal samples and restudy of the original Morton collection using new observational strategies caused other researchers to call into question Morton's conclusions. For instance, in 1857 Daniel Wilson8,9 noted that recently acquired samples from the Western hemisphere did not conform to Morton's definition of American cranial types. Wilson and colleagues concluded that Morton's emphasis upon the fundamental unity of the American race had been overdrawn. New World types were said to be as varied as those of the Old World. J. Aitken Meigs, although initially in support of Morton's theories, also came to question the unity hypothesis. Given responsibility for osteological study of the Morton collection, Meigs7 initiated a new (for the mid-1800s) observational strategy: detailed examination of the occipital bone. The results of this restudy led Meigs to conclusions distinctly different from those of Morton.7

This scenario is, of course, familiar to scholars from any field of scientific inquiry. New knowledge is gained through the refinement of prior models. As more comparative data become available, so do new techniques. An essential aspect of scientific methodology is reexamination of existing theories through the application of innovative research strategies and/or through the availability of an enriched data base. And so it happened in this example from 19th-century physical anthropology, as Morton's theory of racial unity was tested by later scholars and found wanting.

The importance of this illustration is that it underscores the fundamental relationship between availability of museum collections of human skeletal remains and the development of new knowledge in physical anthropology. Although the existence of such a relationship may seem intuitively obvious, the strength of this association remains to be explored. Certainly, other great American skeletal collections could have been cited in our example, including those of the Smithsonian, the American Museum of Natural History, and the Peabody Museum. These collections have served well the needs of generations of physical anthropologists and continue to be used today. In addition to the more familiar skeletal depositories mentioned above, hundreds of collections exist in museums and universities throughout the world. Although some attempts to catalogue human skeletal series on this continent have been completed,10 none has explicitly examined the use and reuse of such collections in the generation of new scientific knowledge.

A major emphasis in this study is longevity of use for skeletal series.
We are all aware that the objectives for collecting osteological materials have changed since Morton's time: from skulls to total recoverable elements; from "representative" adult skeletons to total cemetery samples. Even so, it would be premature to conclude that the older series are not useful in the development of new knowledge. The importance of these older collections requires careful scrutiny, particularly in view of the current disquieting trend toward reburial of human skeletal remains. We will attempt here to examine the pattern of use for the older collections, as well as that for those more recently acquired. In addition, we are concerned with the degree to which older series are important in the development and testing of techniques and methodologies that were not available at the time of collection acquisition.

Finally, we here attempt to quantify the frequency of restudy of existing museum collections, and their role in the reexamination and alteration of formerly accepted conclusions. These data should be important in assessing the usefulness of human skeletal collections to scientific inquiry, and the need for long-term curation of these series.

MATERIALS

To examine the role of museum collections in the generation of new scientific knowledge, we have defined our new knowledge data base as follows: the set of research articles published in the American Journal of Physical Anthropology, American Antiquity, and Human Biology between the years 1950 and 1980 inclusive. Only those articles in which the author physically consulted a museum collection of human remains are included in our sample. Thus reuse of data previously obtained for another project or published elsewhere did not merit inclusion. Similarly, articles referencing data obtained from dental casts and x-rays without assessing the collections per se were also excluded.

Utilizing the 310 articles thus defined, the following eight dimensions of variability were recorded for each study: (1) year of publication, (2) problem orientation, (3) number of collections observed, (4) collection names or numbers, (5) collection sizes, (6) collection acquisition dates, (7) whether the article is a restudy of any collection, and (8) whether the article utilizes analytical techniques not available at the time of collection acquisition. Though these details may seem fundamental, many articles lacked complete information. In such cases, every attempt was made to obtain the necessary data from original site reports or by contacting the author via telephone or mail.
Several attribute states for these variables require additional explanation. A summary of this information appears in Table 1. Problem orientation, for example, was recorded as either descriptive, technical, or investigative. Articles presenting raw data for a particular collection and/or comparing data values among several collections without explicitly referencing an explanatory hypothesis were coded as descriptive/comparative. Projects that accessed collections to illustrate or test a new analytical technique such as blood typing, aging, or sexing, were coded as technical. Research designed specifically to test an a priori hypothesis were coded as investigative. Our purpose in making these distinctions is to isolate the differences in collection use for gaining different types of knowledge.

The number of collections used for a given article is a particularly problematic variable, because the definition of “collection” can vary depending on the author’s research problem. This is especially true for archaeologically derived skeletal series. For example, the Northwestern University skeletons might be referenced as a single collection of Lower Illinois Valley Amerindians when research focuses on regional variability. A second project might recognize the same skeletons as three separate, temporally defined, collections (Archaic, Woodland, and Mississippian) if biological change over time were the focus. Still a third article might recognize 10 or more separate collections, based on individual mounds or mound groupings for research emphasizing intraregional variability in population structure.

### Table 1

**Coding Format**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Attribute States, As Coded</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Year of publication</td>
<td>1950 . . . 1980</td>
</tr>
<tr>
<td>2. Problem orientation</td>
<td>descriptive; technical; investigative</td>
</tr>
<tr>
<td>3. Number of collections accessed</td>
<td>1 . . . n, by series</td>
</tr>
<tr>
<td>4. Collection names/numbers</td>
<td>recorded as given, not analyzed</td>
</tr>
<tr>
<td>5. Collection sizes</td>
<td>1-30; 30-100; 101-300; 301-1000; 1000 + most recent year of acquisition/maceration</td>
</tr>
<tr>
<td>6. Collection acquisition dates</td>
<td>no; yes, new problem; yes, old problem—same conclusions; yes, old problem—new conclusions; old problem—conclusions unclear</td>
</tr>
<tr>
<td>7. Restudy</td>
<td>yes: no</td>
</tr>
<tr>
<td>8. New technique</td>
<td></td>
</tr>
</tbody>
</table>
Recognizing these differences in collection definition, we have recorded all data at the series level. We here define series as the set of human remains from a single archaeological site or closely related sites (such as a mound group), housed in a single institution. Thus the Lower Illinois Valley Amerindians at Northwestern constitute a single collection with a number of series included: Gibson, Ledders, and Koster, for example. Practically speaking, this approach is still not appropriate to the few articles that reference temporally defined series for which individual proveniences have either been lost or were unavailable to us. In these few instances, we have recorded each temporal-cultural unit as a separate series, recognizing that this will cause us to slightly underestimate the actual number of series investigated in some research projects.

Collection size was recorded for each series utilized. Since precise individual counts are very difficult to obtain, this variable was coded as follows: (1) fewer than 30 individuals, (2) 30–100 individuals, (3) 101–300 individuals, (4) 301–1000 individuals, (5) more than 1000 individuals.

Exact acquisition dates were also difficult to estimate, and most series required more than one year to collect. For the purposes of this study, we have used the last year of the acquisition interval as the relevant value. Thus a series excavated or macerated between 1954 and 1959 would have a 1959 acquisition date. If an article was published before collection was complete, the acquisition date for that particular sample was recorded as one year less than the publication date. The choice of analysis at the series level is particularly important to this variable, since large skeletal collections may have a number of series acquired at quite different times.

Finally, the attribute restudy was also coded in several variables states. A series is restudied by recording data classes previously collected by someone else. This may be for a new research problem, or an old problem may be restudied. When an old problem was reinvestigated, the results were coded as either confirmation or rejection of previous conclusions. Thus restudy has the following values: (1) no; (2) yes, new problem; (3) yes, old problem and new conclusions; (4) yes, old problem and same conclusions; and (5) yes, old problem with conclusions unclear.

METHODS OF DATA ANALYSIS

Using the eight variables defined above, four aspects of collection use were investigated: (1) longevity of collection use, (2) restudy of older col-
lections, (3) utilization of multiple collections for comparative data, and (4) size of collections and frequency of their use.

LONGEVITY

Three approaches were used to investigate collection longevity. For a general impression of collection use in the last 30 years, we have generated a bivariate scattergram of publication year against acquisition year for each series included in our sample. This strategy is used to answer the question of whether older collections are still in frequent use.

To see how these older series are being used, we have utilized a cross-tabulation table showing the frequency of collection use for each type of problem orientation by the collection's age at the time of use. To do this, we defined a new variable, Age, by subtracting acquisition year from publication year. This table should clearly answer the question of whether older collections are being used in the problem-oriented, population-based research of the last 30 years. In addition, the role of older collections in the development and testing of new techniques can be assessed from this table.

COLLECTION REUSE

The frequency with which older series are restudied is of primary consideration in long-term curation planning. The frequency of reuse in this sample was investigated in several ways. Overall frequencies of reuse were generated using the SPSS program Frequencies. This tabulation provides a measure of data recollection with new research problems in mind, and of the reinvestigation of prior conclusions. To see how long series continue to be reused, frequency of reuse by age of series was also calculated. This should indicate whether older series are considered valuable for the reinvestigation of biological/cultural theories.

The role of restudy was also considered for each type of problem orientation in our sample. A $\chi^2$ test was used to assess the significance of any differences in restudy frequency between descriptive, technical, and investigative projects. These results should provide a general indication concerning what kind of scientific information can be expected through reuse of collections in long-term curation.

The development of new techniques figures prominently in the reuse and longevity of museum collections. This final aspect of reuse was investigated by examining the frequency with which our restudy series
were analyzed using techniques not available at the time of their acquisition. Of particular scientific importance is the frequency of conclusion reversals and significant alterations when new techniques are applied to older series.

THE NEED FOR COMPARATIVE DATA

A third important aspect of long-term curation is the need for comparative data when new collections become available. The importance of comparative data to the generation of new scientific information was assessed by computing the mean number of series reported in each article. It was anticipated that the need for comparative data might vary with problem orientation. A Model I Analysis of Variance\textsuperscript{11,12} was chosen to test this hypothesis. Preliminary tests, however, indicated that the Number of Series variable was not normally distributed. Thus a Kruskal-Wallis test\textsuperscript{11,12} was substituted for the Anova. This procedure supplies the same statistical information as a single classification Anova, but without assumptions about the distribution of the dependent variable.\textsuperscript{12}

Our choice to analyze these data at the series level becomes critical here, since there is a "convenience bias" introduced when many skeletal series spanning a long time interval are available in a single museum. The California Indian Collection at the University of California at Berkeley is a case in point. Authors without access to such a large, temporally complete collection would have to use several different collections in order to get the same amount of comparative data that one trip to the Lowie Museum could provide. By treating these large collections as groups of skeletal series, we have tried to avoid a convenience bias in our data.

COLLECTION SIZE

A final aspect of collection longevity and usefulness is size of the collection. Here we considered the relative importance of collection size to the development of new knowledge. To investigate this relationship, we again applied the SPSS program Frequencies to the variables Size, and used a \(\chi^2\) test of significance.\textsuperscript{11} As restudy is a very important variable in assessing the value of long-term curation and the development of new knowledge, frequency of restudy by size of series was also tested for significance.
Figure 1. Bivariate scattergram of acquisition date vs. publication date.
RESULTS

LONGEVITY

Figure 1 is a bivariate scattergram of series acquisition dates plotted against publication dates for our sample. Clearly, older collections are still being used in recent research. In fact, use of series acquired before 1930 seems to have increased considerably in the 1970s. Although recent collections are obviously more frequently used, this is at least partially an artifact of sampling strategy. The 1950 starting date eliminates many articles based on older series that were published shortly after their acquisition.

The relative paucity of collections acquired between 1941 and 1955 is quite obvious in Figure 1. This is undoubtedly an effect of World War II and the Korean Conflict. It should be noted that many articles published during and shortly after this period were based upon data derived from war dead. Since these individuals were later returned to their families, and are therefore not collections as defined in this study, those projects were not included in our sample.

A frequency cross-tabulation of series age by problem orientation is presented in Table 2. Inspection of the column frequencies and total indicates that most collections referenced in the last 30 years were used for investigative problems ($\chi^2 = 139.46, p < .001$). This undoubtedly reflects both a recent trend in anthropological research, and an apparent preference for nondescriptive articles on the part of the three journals chosen. It is also clear that use of older series is not limited to descriptive and technical research. In fact, after the first 30 years of curation, investigative research is unquestionably the predominant reason for study-

<table>
<thead>
<tr>
<th>Series Age</th>
<th>Descriptive</th>
<th>Technical</th>
<th>Investigative</th>
<th>Row Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10 years</td>
<td>60</td>
<td>16</td>
<td>86</td>
<td>162</td>
</tr>
<tr>
<td>11-20 years</td>
<td>22</td>
<td>13</td>
<td>47</td>
<td>82</td>
</tr>
<tr>
<td>21-30 years</td>
<td>16</td>
<td>12</td>
<td>16</td>
<td>44</td>
</tr>
<tr>
<td>31-40 years</td>
<td>9</td>
<td>8</td>
<td>53</td>
<td>70</td>
</tr>
<tr>
<td>41-50 years</td>
<td>22</td>
<td>12</td>
<td>42</td>
<td>76</td>
</tr>
<tr>
<td>50+ years</td>
<td>8</td>
<td>5</td>
<td>29</td>
<td>42</td>
</tr>
<tr>
<td>Column Totals</td>
<td>137</td>
<td>66</td>
<td>273</td>
<td>476</td>
</tr>
</tbody>
</table>
Figure 2. Restudy of skeletal series.
ing these series. Furthermore, series studied over 50 years after acquisition date contributed to 11% of all the investigative uses of museum collections in this sample.

The decline of descriptive use in relationship to age of series is not unexpected. It is probable that most descriptive articles referencing older collections would predate our 1950 starting date. Unlike descriptive and investigative uses, technical use of museum collections seems evenly represented in all age categories. This impression is supported by a $\chi^2$ test which was not significant at the .05 level ($\chi^2 = 6.90$, df = 5). Thus, older museum collections appear to be equally useful for technical research.

**REUSE**

Reuse of museum collections is summarized in Figure 2. Fully 32% of the cases in our sample involved re-collection of data. Of these 288 reinvestigations, 63% used the data for new research problems and 37% restudied the conclusions of earlier reports. When a research problem was reexamined, new conclusions were reached in 62% of the cases, and the status of 31% of the reinvestigation results was unclear. On the basis of this 62% reversal rate for conclusions, we can certainly support the notion that restudy of museum collections is important in the scientific development of knowledge.

Frequency of reuse by collection age and problem orientation is presented in Table 3. The row totals suggest museum collections of all ages were equally restudied. This idea is supported by a $\chi^2$ test which was not significant at the .05 level ($\chi^2 = 10.1$, df = 5). Although not statistically significant, the relatively higher reuse rate for collections

<table>
<thead>
<tr>
<th>Series Age</th>
<th>Descriptive</th>
<th>Technical</th>
<th>Investigative</th>
<th>Row Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10 years</td>
<td>4</td>
<td>3</td>
<td>16</td>
<td>23 (17%)</td>
</tr>
<tr>
<td>11–20 years</td>
<td>6</td>
<td>4</td>
<td>6</td>
<td>16 (12%)</td>
</tr>
<tr>
<td>21–30 years</td>
<td>8</td>
<td>4</td>
<td>9</td>
<td>21 (15%)</td>
</tr>
<tr>
<td>31–40 years</td>
<td>2</td>
<td>3</td>
<td>25</td>
<td>30 (22%)</td>
</tr>
<tr>
<td>41–50 years</td>
<td>12</td>
<td>5</td>
<td>14</td>
<td>31 (23%)</td>
</tr>
<tr>
<td>50+ years</td>
<td>3</td>
<td>1</td>
<td>11</td>
<td>15 (11%)</td>
</tr>
</tbody>
</table>

| Column Totals | 35 (26%) | 20 (15%) | 81 (59%) | 136 (100%) |
31–50 years old can probably be attributed to the disproportionate reuse of the Terry Collection (macerated 1910–1940), the Indian Knoll Series at the University of Kentucky (excavated 1939–1941), and the various Eskimo and Aleut series collected by Hrdlička, Collins and others that are housed at the Smithsonian (1926–1939).

A consideration of column totals in Table 3 suggests that most restudies were undertaken for investigative purposes. Investigative problems made up 59.6% of the restudies, with 25.7% descriptive, and 14.7% technical in focus. These differences are significant at the .001 level ($\chi^2 = 45.03$, df = 2). In sum, reuse of series that are available for long-term study can be expected to figure prominently in the development of new scientific knowledge and particularly so in investigative research.

The development of new techniques (summarized in Fig. 3) is an important factor that should influence decisions made concerning long-term curation and maintenance of museum collections. In our sample, 25.8% of the skeletal series were studied using techniques not available at the time of acquisition. The application of new techniques is even more frequent in the series restudy subsample (see Fig. 3). Nearly half of the cases of series restudy (47.9%) utilized new techniques. When new techniques were applied to reinvestigations of old problems, new conclusions were reached in 73.7% of the cases. This startling figure clearly indicates that long-term curation of human remains is quite important in the development of new knowledge.

COMPARATIVE USE

The desirability of comparative series for scientific research is an important reason for a broad commitment to long-term curation of human skeletal remains. Fully 47% of the articles sampled here were based upon such comparative use. Descriptive statistics for the Number of Series Used variable are presented in Table 4. Articles in this sample utilized between one and 55 series. The mean number of series used was 3.2, but this figure varied broadly, resulting in a standard deviation of 5.2. In addition, the distribution of this variable is skewed to the right and is leptokurtic, with both statistics significant at the .001 level.

To understand better what types of scientific research are most benefited by multiple series use, we compared the number of series used across descriptive, technical, and investigative problem orientations. The results of this Kruskal-Wallis test are presented in Table 5. In-
OLD TECHNIQUES
N=112 (52%)

NEW RESEARCH PROBLEMS
N=46 (45%)

CONCLUSIONS CONFIRMED
N=0 (0%)

CONCLUSIONS ALTERED
N=57 (55%)

CONCLUSION STATUS UNCLEAR
N=15 (26%)

NEW TECHNIQUES
N=103 (48%)

OLD PROBLEMS
N=57

CONCLUSIONS ALTERED
N=42 (74%)

CONCLUSION STATUS UNCLEAR
N=15 (26%)

FIGURE 3. Applications of new techniques to skeletal research.
Table 4

**DESCRIPTIVE STATISTICS FOR NUMBER OF SERIESUsed**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>292</td>
</tr>
<tr>
<td>Missing cases</td>
<td>18</td>
</tr>
<tr>
<td>Minimum</td>
<td>1</td>
</tr>
<tr>
<td>Maximum</td>
<td>55</td>
</tr>
<tr>
<td>Mode</td>
<td>1</td>
</tr>
<tr>
<td>Mean</td>
<td>3.22</td>
</tr>
<tr>
<td>Standard of deviation</td>
<td>5.17</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>160.8</td>
</tr>
<tr>
<td>Skewness (g')</td>
<td>5.48*</td>
</tr>
<tr>
<td>Kurtosis (g^2)</td>
<td>41.29*</td>
</tr>
</tbody>
</table>

*p < .001.

Investigative articles clearly use more comparative series than technical and descriptive articles, and this difference is significant at the .001 level. Thus, long-term curation can be expected to benefit all types of skeletal research by making comparative series available for study, but investigative research will be particularly enhanced by this.

**COLLECTION SIZE AND FREQUENCY OF USE AND REUSE**

Figure 4 illustrates the relationship between series size and frequency of use. As might be expected in a sample of post-1950 research projects, the larger series (101-1000) are the most frequently represented ($\chi^2 = 51.2, p < .001$). This is probably related to the development of population biology and the high-speed computer, which make large sample sizes both desirable and manageable in research. The lower frequency of very large series (1000+) is probably more a function of their scarcity than of lack of utility. Even though larger series are more frequently represented,

Table 5

**KRUSKAL-WALLIS ONE-WAY ANOVA**

<table>
<thead>
<tr>
<th>Problem Orientation</th>
<th>N</th>
<th>Mean Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive</td>
<td>102</td>
<td>123.35</td>
</tr>
<tr>
<td>Technical</td>
<td>49</td>
<td>123.95</td>
</tr>
<tr>
<td>Investigative</td>
<td>141</td>
<td>171.09</td>
</tr>
</tbody>
</table>

$\chi^2 = 27.3; p < .001.$
collections numbering fewer than 100 still accounted for 26.5% of series use. Clearly, smaller series are contributing significantly to the development of new scientific knowledge.

Restudy of collections by size is illustrated in Figure 5. While larger series experience a greater frequency of reuse ($\chi^2 = 34.4, < p .001$), again small collections are significantly represented. Series numbering 100 or fewer accounted for 21% of the reinvestigations. This demonstrates that small samples, while perhaps not ideal for population-oriented research, are nonetheless contributing significantly to new insights concerning skeletal biology. The quality of future scientific research thus depends upon the inclusion of small series in plans for long-term curation of skeletal collections.

SUMMARY AND CONCLUSIONS

We have here investigated the relationship between long-term availability of human skeletal remains and the development of new knowledge in physical anthropology. Using studies published during the last 31 years in three North American journals, we have coded data that define collection size and acquisition dates, as well as the nature of the research pro-
ject. Problem orientation and the reuse of collections received particular emphasis, as did the application and development of new analytical techniques.

Our data clearly support the notion that efforts made to conserve and store human skeletal collections are beneficial to the development of scientific knowledge. Older collections are being used, particularly in problem-oriented, investigative research. The fact that replicability and validation, crucial concepts in all scientific inquiry, require long-term availability is further reinforced by our research results, which indicate that restudy of collections often produces significant modification of previously accepted conclusions. This trend is particularly prominent when the results of prior inquiries are examined using new analytical techniques. Recent investigative problem-oriented research has been considerably enhanced by the presence of collections accessioned 50 or more years ago. These older series are also frequently used in the development of new techniques, and in comparisons with more recently collected samples. And, even though the larger series figure prominently in recent studies, it is important to note that collections numbering fewer than 100 individuals are commonly used both in initial investigations and in the restudy of contemporary hypotheses.
This research effort was initiated as a means of exploring the relation-
ship between recent anthropological studies and the use of older collec-
tions of human remains. The goal was to provide information that would
be useful to individuals who plan curation strategies. Our results clearly
indicate that the present generation of scholars has benefited significantly
from the considerable efforts made by workers who have—since
Morton's time—systematically collected and curated human remains. It
is our responsibility to ensure that future generations of scholars are
allowed a similar privilege.

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